LHC COLLIMATORS WITH EMBEDDED BEAM POSITION MONITORS: A NEW ADVANCED MECHANICAL DESIGN

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Abstract

The LHC collimation system, ensuring both functions of beam cleaning and machine protection, is potentially submitted to high-energy beam impacts. Currently the collimators setup is performed by monitoring beam losses generated by the collimator jaws when approaching the particle beam. This procedure is applied to all LHC collimators (almost one hundred), taking several hours, and needs to be repeated if beam settings change significantly. Furthermore, during the beam-based alignment, the LHC tertiary collimators are potentially exposed to abnormal losses entailing possible damage to their tungsten jaws. To improve the efficiency of the machine operation and better control the particle beam a new advanced design embedding Beam Position Monitors (BPM) into the movable collimator jaws has been developed. This paper describes the mechanical design of various types of future collimators with embedded BPMs. Experimental measurements performed on a simplified functional prototype installed in the CERN SPS showed that, thanks to on-board BPMs, the collimator could be precisely, rapidly, and safely aligned and the beam position accurately measured.

INTRODUCTION

The almost achievable cleaning efficiency of the present LHC collimators is associated with gap size accuracy as well as with precision of jaw centring and parallelism with respect to the beam. The reproducibility and stability of the collimation positioning are important to avoid repeating beam-based alignment which is a lengthy procedure taking almost 36 hours of beam time [1]. For this reason, a drastic reduction of the collimator setup time has become one of the main objectives for the LHC collimation system upgrade [2]. To satisfy this challenging requirement, a joint effort from mechanical design and beam instrumentation experts developed the idea of movable jaws with embedded beam diagnostics virtually enabling an automatic alignment of the collimators.

EMBEDDED BPM CONCEPT

The basic idea is to integrate BPMs into the movable jaws to continuously monitor the position of the particle beam and accordingly adjust the collimation setup. Mechanical integration is a crucial point given the limited space available inside the collimators' vacuum tank. For this reason, pickups with optimized dimensions have been designed (Fig. 1). Furthermore, coaxial cables carrying BPM signals, flanges with special feedthroughs, as well as BPM electrodes, must meet all the collimator requirements in terms of UHV compatibility, radiation hardness, and bake-out cycles (up to 300 ºC) [3].

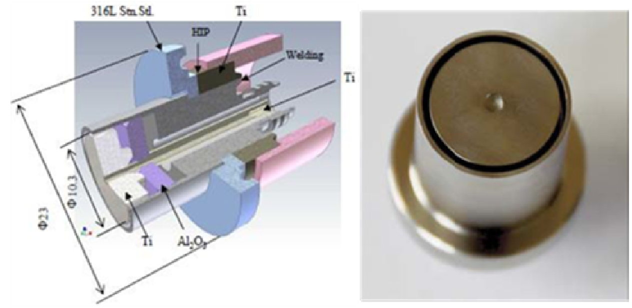

Figure 1: Beam Position Monitor (BPM) for the LHC collimators.

BPM Demonstrator

The first collimator mock-up embedding BPMs was installed in the SPS ring at the beginning of 2010 for beam testing.

In its initial concept, the BPM demonstrator featured 4 pickups on each jaw, one for each extremity and two in the centre (Fig. 2). Nonetheless, the experience gained from this mock-up, showed that two sensors per jaw are sufficient for the alignment while the buttons in the middle of the jaws were not effective.

Installing the BPM in the tapering region, at the jaw ends, is the best compromise between space constraints and signal quality. Besides, with the tapering up to 10mm away from the active surface of the jaw, buttons are somehow protected from possible beam impacts.

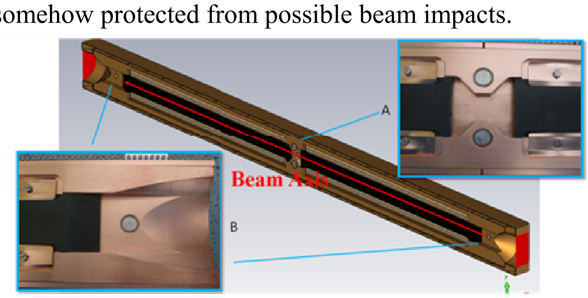

Figure 2: Jaw mock-up embedding four BPMs.

The geometry of the tapering made from a decent electrical conductor must be optimized using CST electromagnetic simulations to maximize the quality of the BPM signal as detailed in Ref. [4]. Furthermore, the surface of each button must be precisely positioned with respect to the surrounding surface: an accurate positioning system has been developed as described hereafter (Fig. 3).

The BPM demonstrator was tested both in the laboratory and the SPS ring presenting exceptional results; the actual position of the jaws can be read via precise sensors installed in the actuation system (as it is for present collimators), while the jaws can be accurately centred around the particle beam zeroing the signal which comes from each pair of pickups [3] [4].

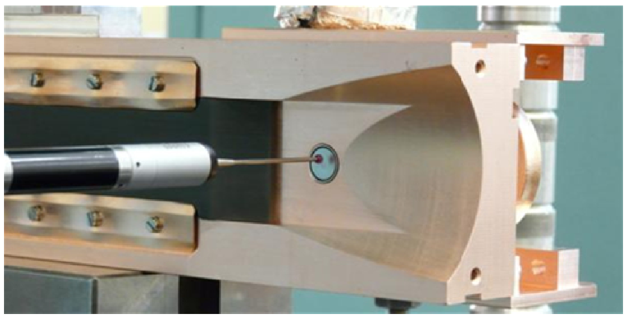

Figure 3: Metrology control of jaw mock-up to check the alignment of the BPM button surface with respect to the surrounding tapering.

Eventually, the so-called "BPM demonstrator" achieved its goal proving that, thanks to on-board BPMs, the collimator mock-up could be precisely and rapidly aligned with respect to the beam [3].

MECHANICAL DESIGN

This concept has been improved and is actually part of several families of future devices such as the phase II collimators [5], as well as the special collimator for cold regions (to possibly be installed, in the future, in the LHC dispersion suppressor) [6].

Moreover, recent studies [7] [8] confirm that embedded BPMs would allow a more precise collimation setup with clear advantages not only in terms of setup time but also in terms of luminosity and reliability of LHC operation, thus the integration of BPMs into the collimator jaws has been identified as a priority for the LHC upgrade; the deployment of these new collimators is to start during next long shutdown. A development programme is in progress to achieve the tight deadlines imposed by the collimation system update: upgraded mechanical design of phase I tertiary collimators including BPMs is presently being released while the upgrade study is starting for primary and secondary collimators.

Tertiary Collimators Embedding BPMs (TCTP)

The mechanical design of TCTP jaws relies on the phase I concept: monolithic jaws made from copper alloy with tungsten alloy inserts. Jaw tapering has been fully redesigned to house the pickup and its shape is optimized to allow image current flowing around the button for a high quality signal; BPMs with their fine positioning system are bolted onto the jaw stiffener (Fig. 4).

The cooling system is also based on the phase I concept. However, the pipe layout has a special shape to correctly house the BPM assembly and to cool the surrounding region (Fig. 4).

The vacuum tank has been slightly modified to include special flanges with electrical feedthroughs carrying the pickup signal (Fig. 5). Particular attention has been paid to the layout of the coaxial cables which are in fact rigid pipes of 2 mm in diameter [3]; bending radii, supports, and connectors have been carefully studied to avoid unfastening and limit stress levels inside the cables (Fig. 6). Considering the required lifetime of 30'000 cycles with a 35 mm jaw stroke, a fatigue analysis has been performed to exclude any risk of cable failure. Endurance tests will later be carried out on a full prototype. Coaxial cables are filled with inert gas (such as Argon or Neon) to improve electrical insulation and signal quality; though cables are compatible with UHV requirements, potential risk of leak of this gas is currently under investigation.

The RF system of TCTP collimators relies on the phase II concept [5] including ferrite tiles to absorb possible HOM; studies are ongoing to confirm the reliability of ferrite tiles with respect to RF contact fingers.

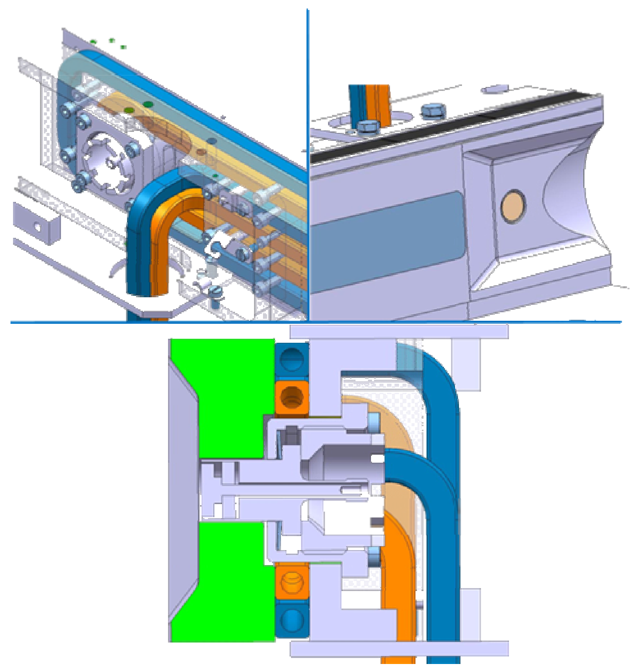

Figure 4: Jaw tapering of future LHC tertiary collimators with BPM housing and fine positioning system.

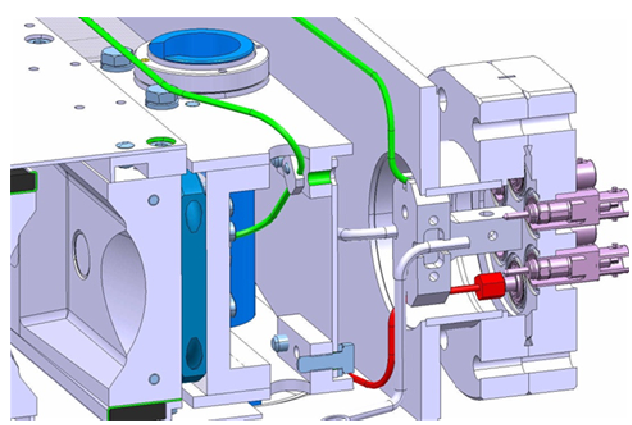

Figure 5: Cross-section of special flange with BPM cable feedthroughs.

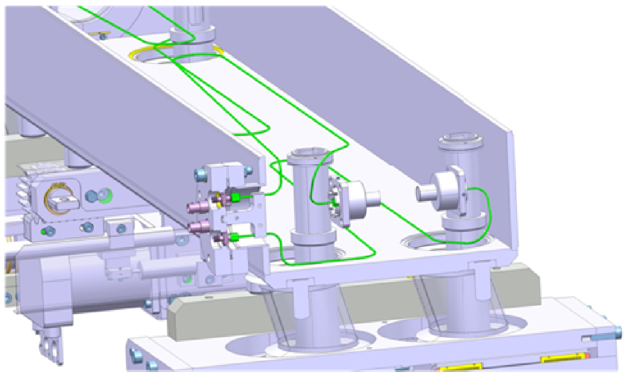

Figure 6: Vacuum tank with layout of coaxial cables and pickup assembly.

Phase II Collimators

Phase II collimators have a completely new design compared to phase I [5]. The three-sector jaw has separated tapering to allow easy shape optimization; BPMs with fine positioning systems are bolted onto a support obtained by extending the two coolers at the extremities (see Fig. 7). The entire system is supported and aligned on the rigid back-stiffener. A phase II collimator prototype has been manufactured and assembled at CERN, ready for testing.

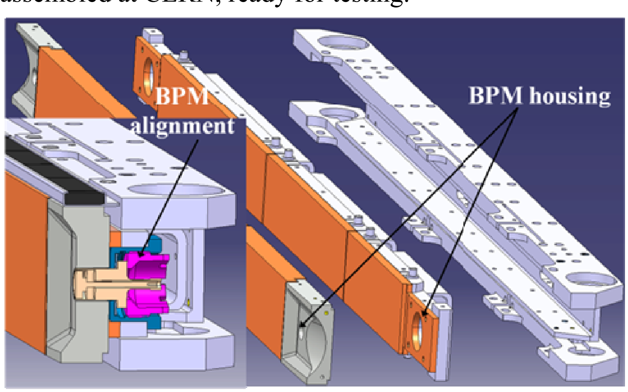

Figure 7: Phase II collimator jaws: tapering with housing and fine positioning system for BPMs.

Dispersion Suppressor Collimator

The special collimator for the LHC Dispersion Suppressor regions (TCLD) features jaws reduced in height. The shape of the tapering as well as the fine positioning system for the BPMs have been adapted to this particular configuration (Fig. 8).

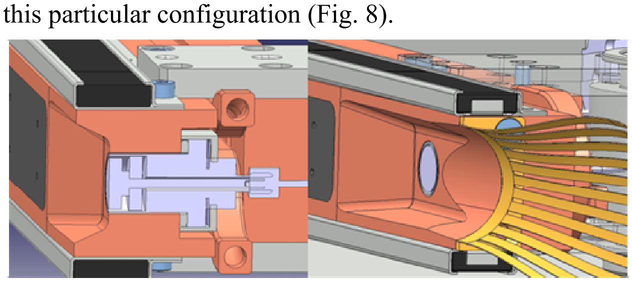

Figure 8: Special collimator for dispersion suppressor (TCLD) embedding BPMs.

CONCLUSIONS

The idea of a collimator with an embedded BPM system relies on a simple and versatile concept which can virtually be extended to any variant of the LHC collimators. However, particular attention should be paid to several design details in order to meet requirements in terms of UHV compatibility, radiation hardness, and robustness.

Both laboratory tests as well as beam experiences performed on the collimator demonstrator showed that jaws embedding BPMs could be precisely, rapidly, and safely aligned and the beam position accurately measured with a precision of a few micrometers.

These encouraging results led to an intense design activity, which is still ongoing, to integrate BPMs not only in future collimators but also to upgrade the existing collimation system.

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